U.S. Department of Energy
Energy Efficiency and Renewable Energy

federal energy management program

DER Technology Overview

Distributed Generation and Combined Heat and Power Workshop
(On-Line)
April 20, 2004

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Distributed Generation Terminology

- DG, DER
  - What is Distributed Generation?
  - Difference between DG and DER

- Microgrids and Power Parks
  - Are they different?

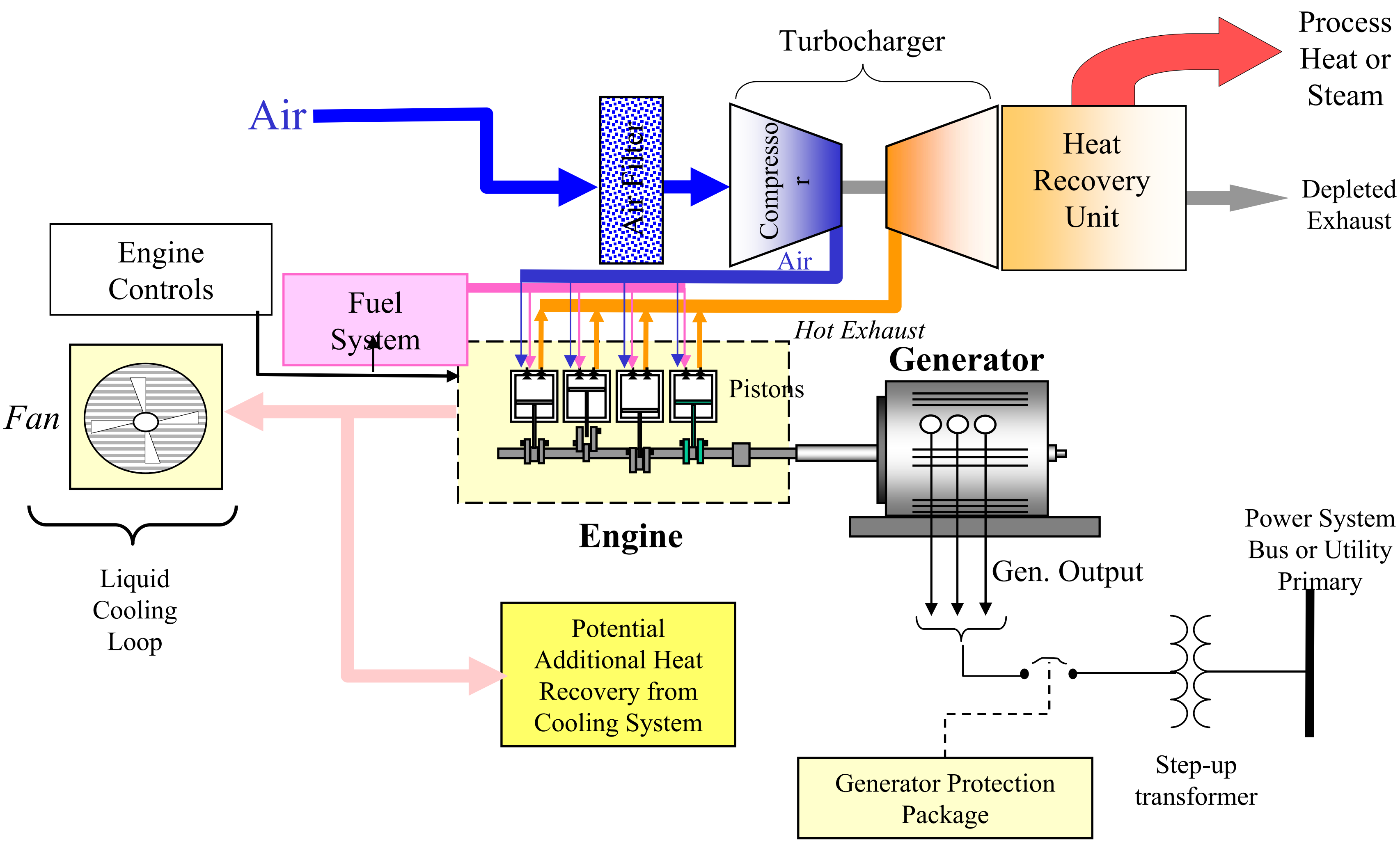
Distributed Generation Technologies

- Reciprocating Engines
- Combustion Turbines
- Microturbines
- Fuel cells
- Energy Storage
- Photovoltaics
- Wind
- Hybrids
- Others

Outline of Segment

- Schematics and functional detail of technologies
- Commercial readiness and some manufacturers
  - Models and sizes
- Cost and Performance
  - FEMP Table

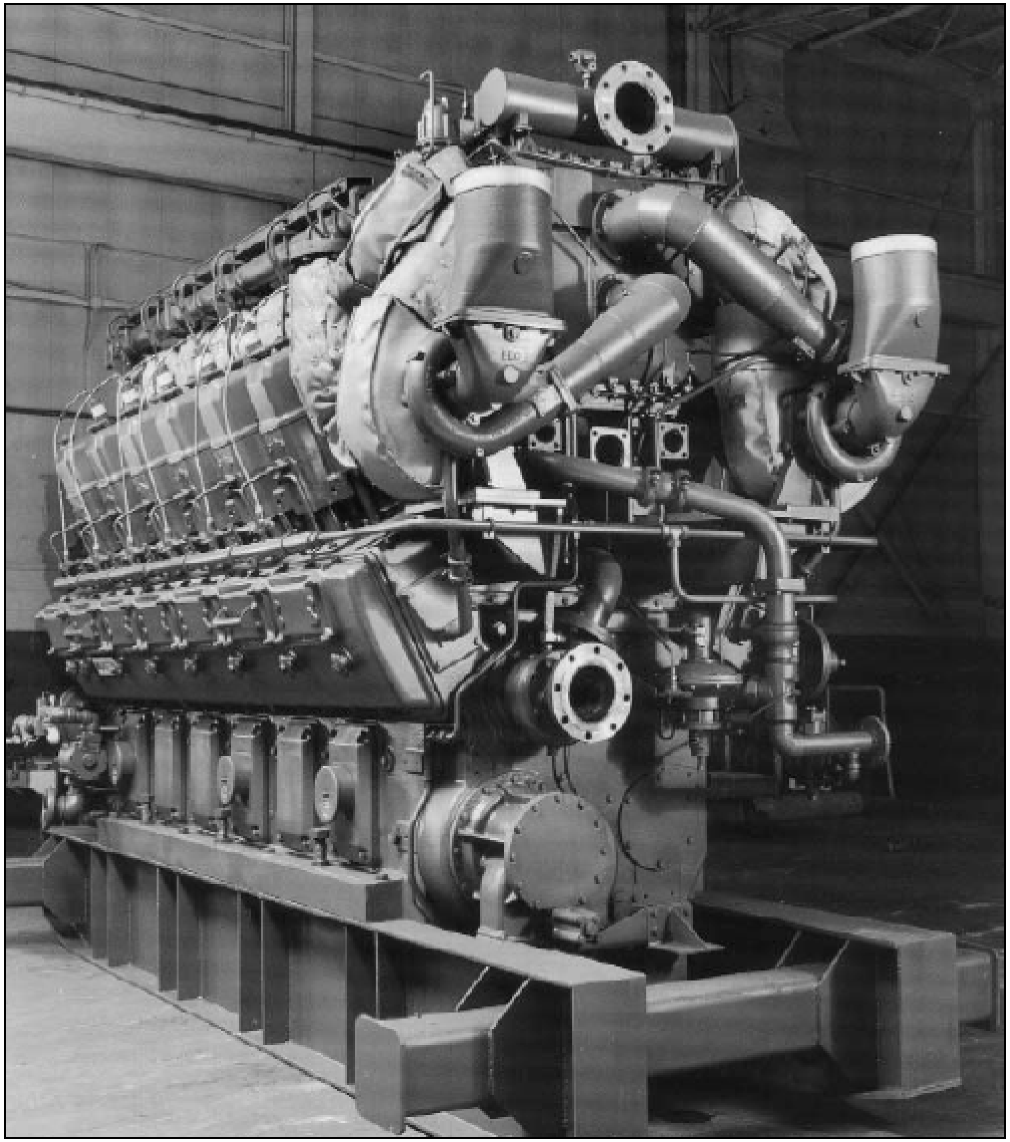
Schematic of Reciprocating Engine

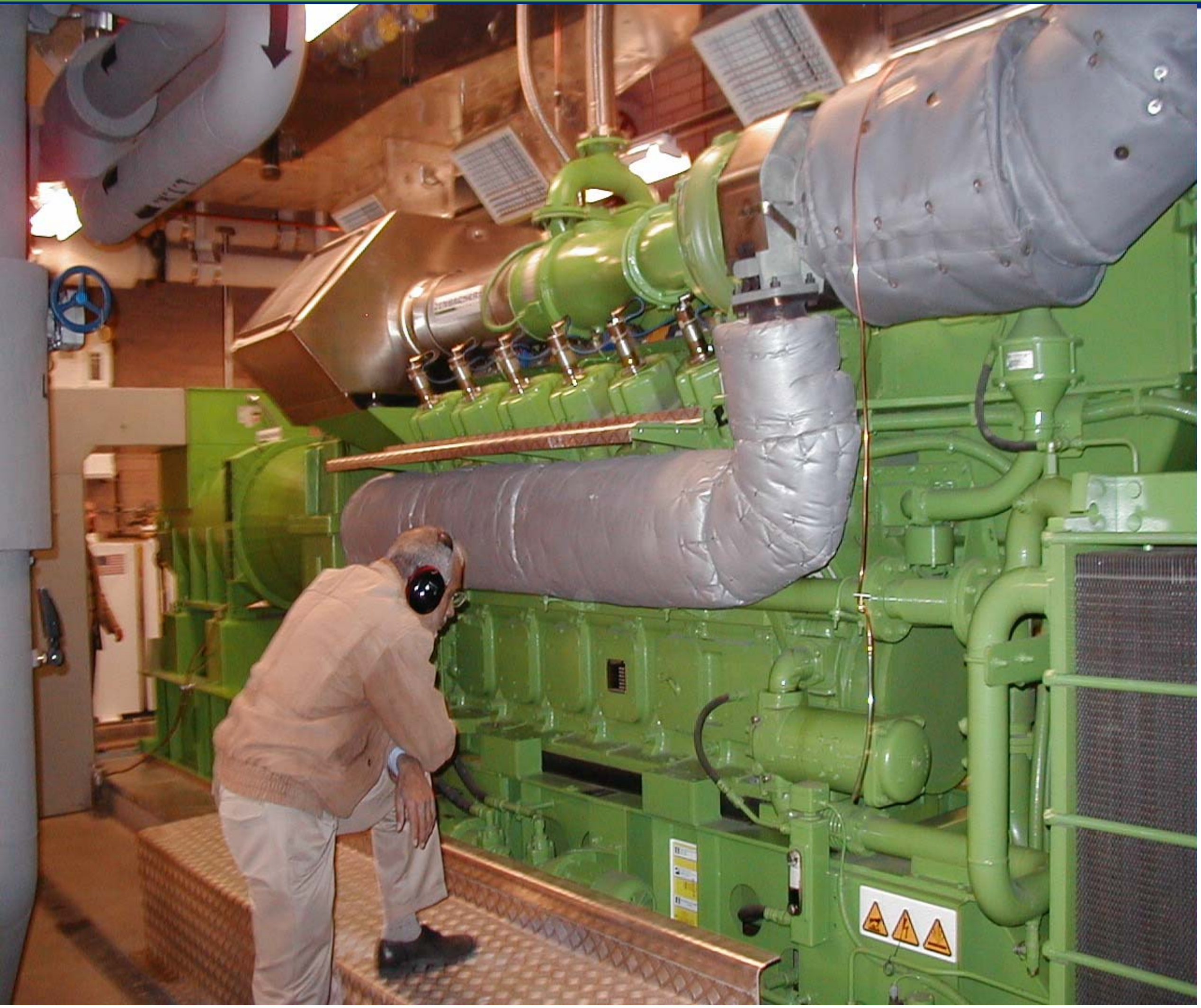


Commercial Readiness and Manufacturers: Reciprocating Engines

- Fuels: Diesel, Natural Gas and Biogas
- Mature commercial technology
  - Well established worldwide manufacturing/service base
  - Over 60 GW of installed capacity in the US alone

Manufacturer: Waukesha
Fuel: Natural Gas
RPM: 750 – 1,000
Rating 1,500 – 2,000 kW
Heat Rate: 9,500 – 9,900 btu/kWh
Duty: Continuous





Owner: City of Tucson

Manufacturer: Jenbacher/GE

Fuel: Natural Gas

Rating 1,600 kW

Heat Recovery: 4.3 mmBTU/hr

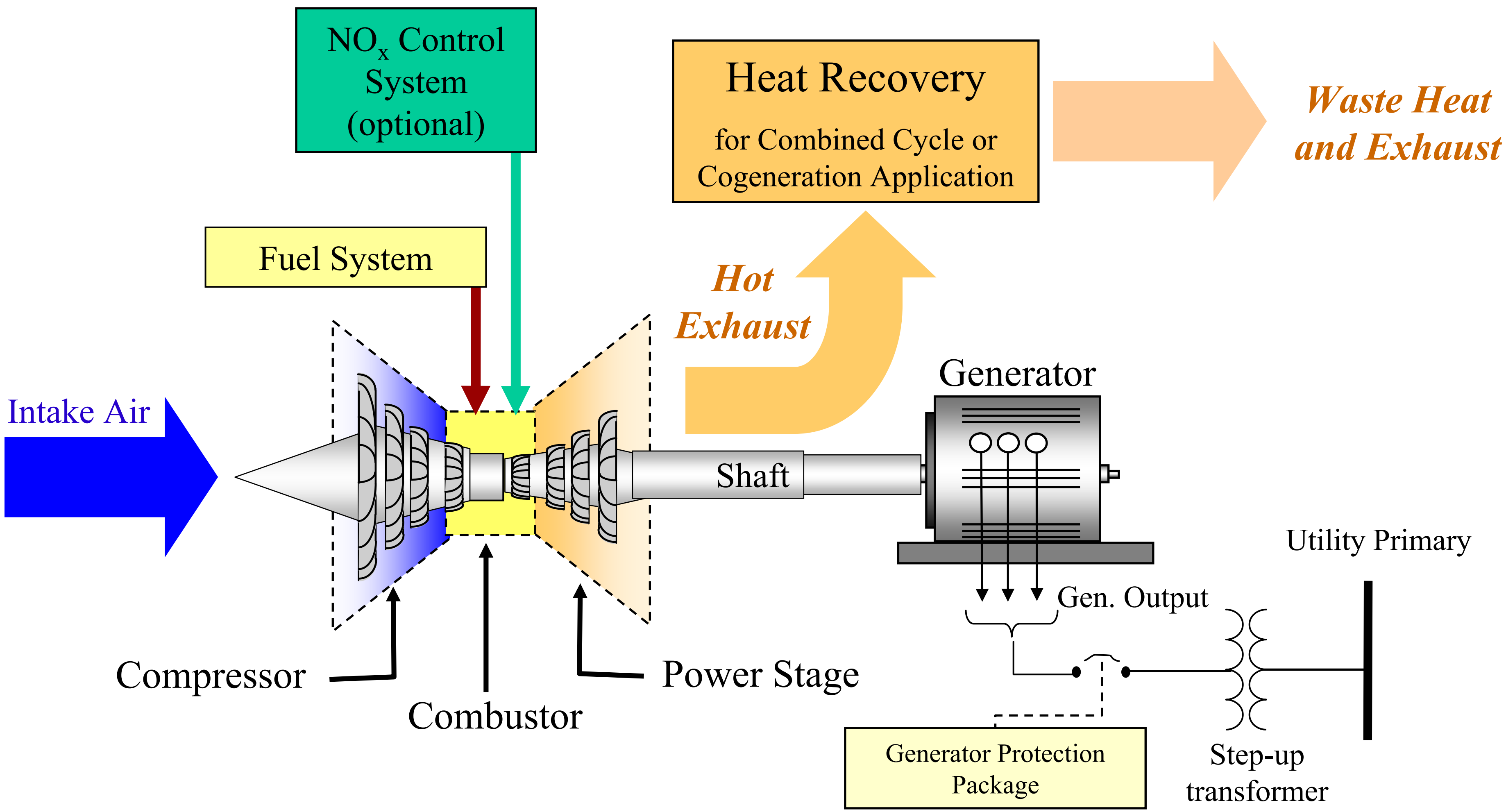
Duty: Continuous

Application: Cogen/Secure Power

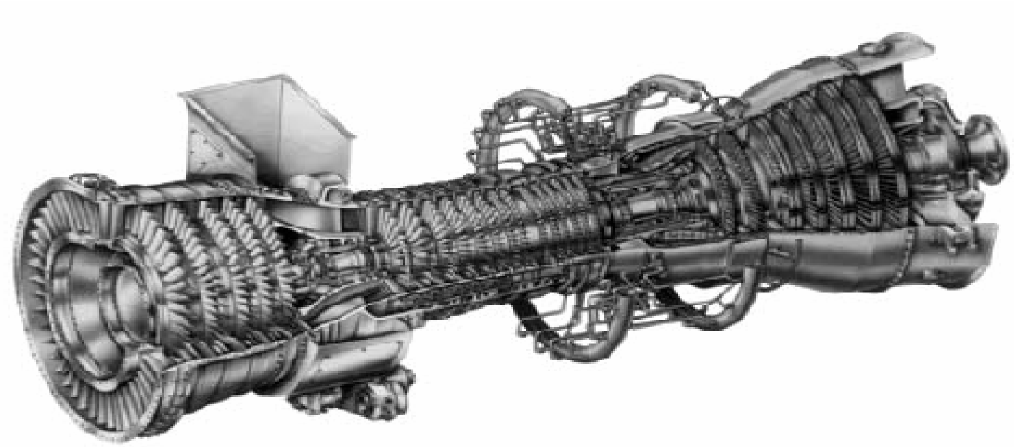
Commissioned: January, 2003


CAT
CAT
CAT

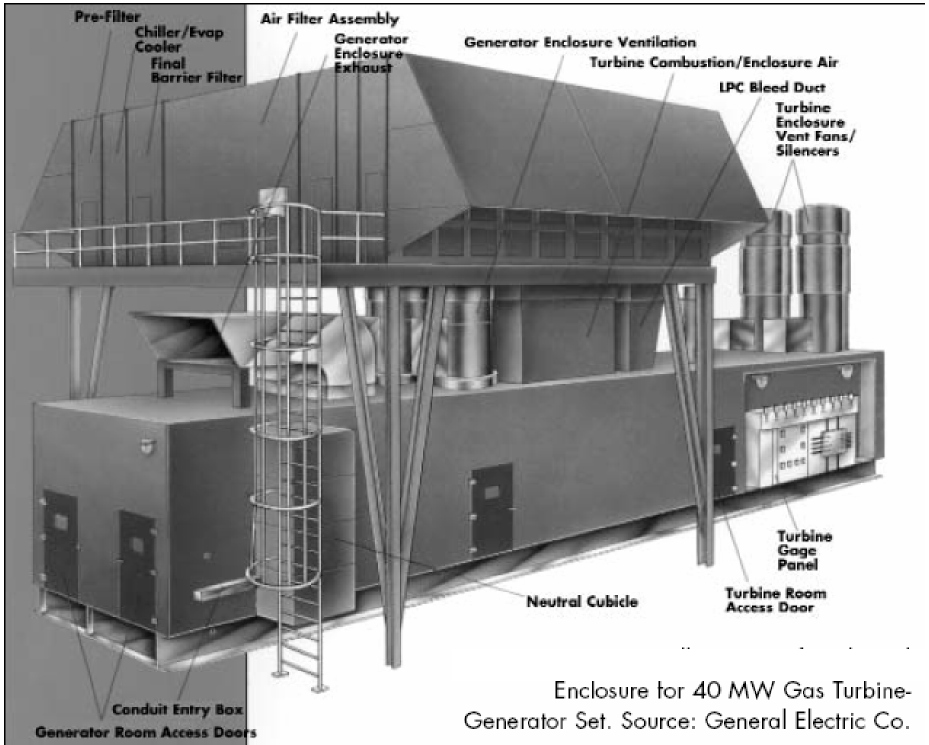
Schematic of Combustion Turbine



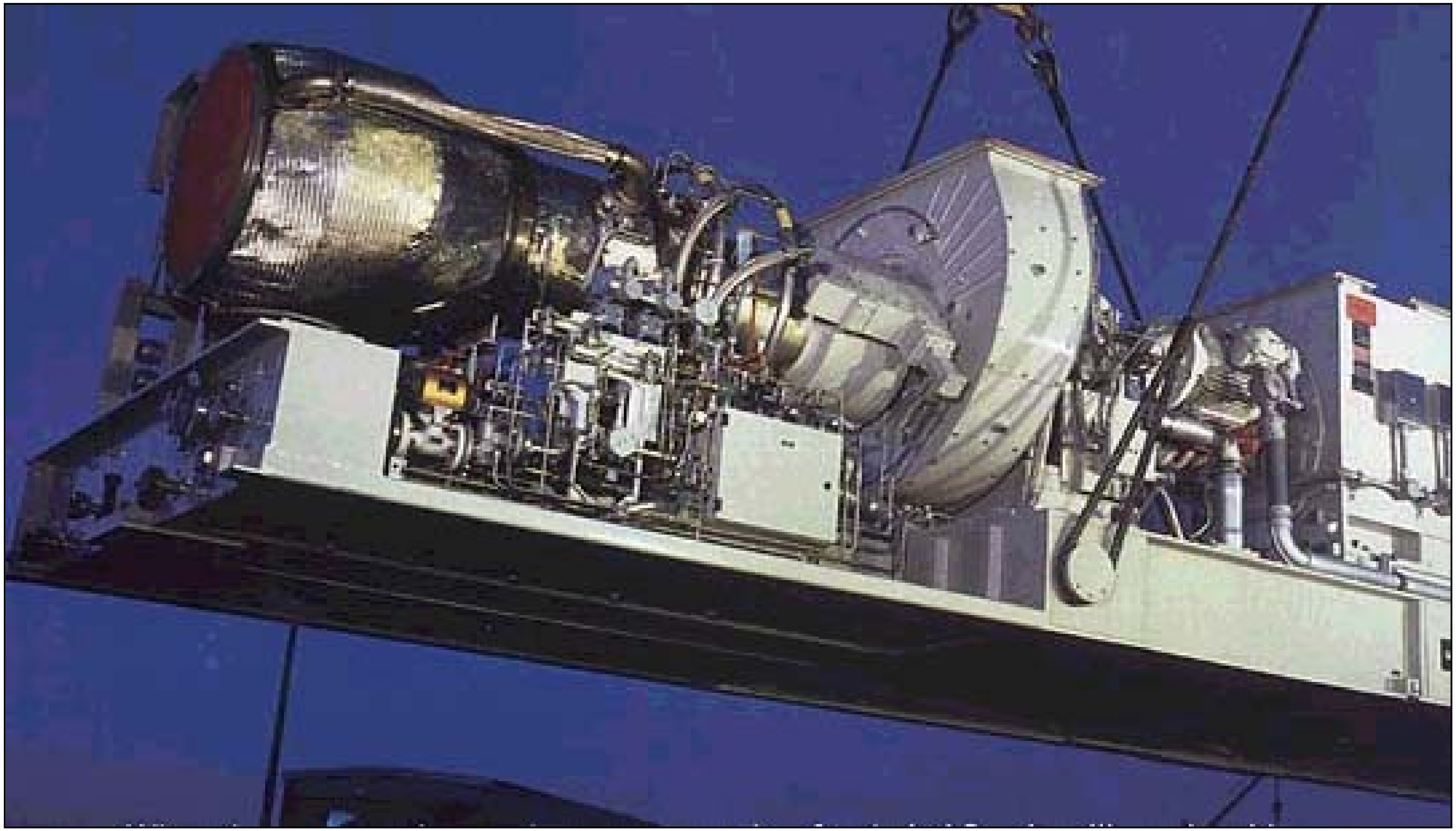
Manufacturer: General Electric
Model: LM6000
Rating: 42 MW
Heat Rate: 10,000 btu/kWh



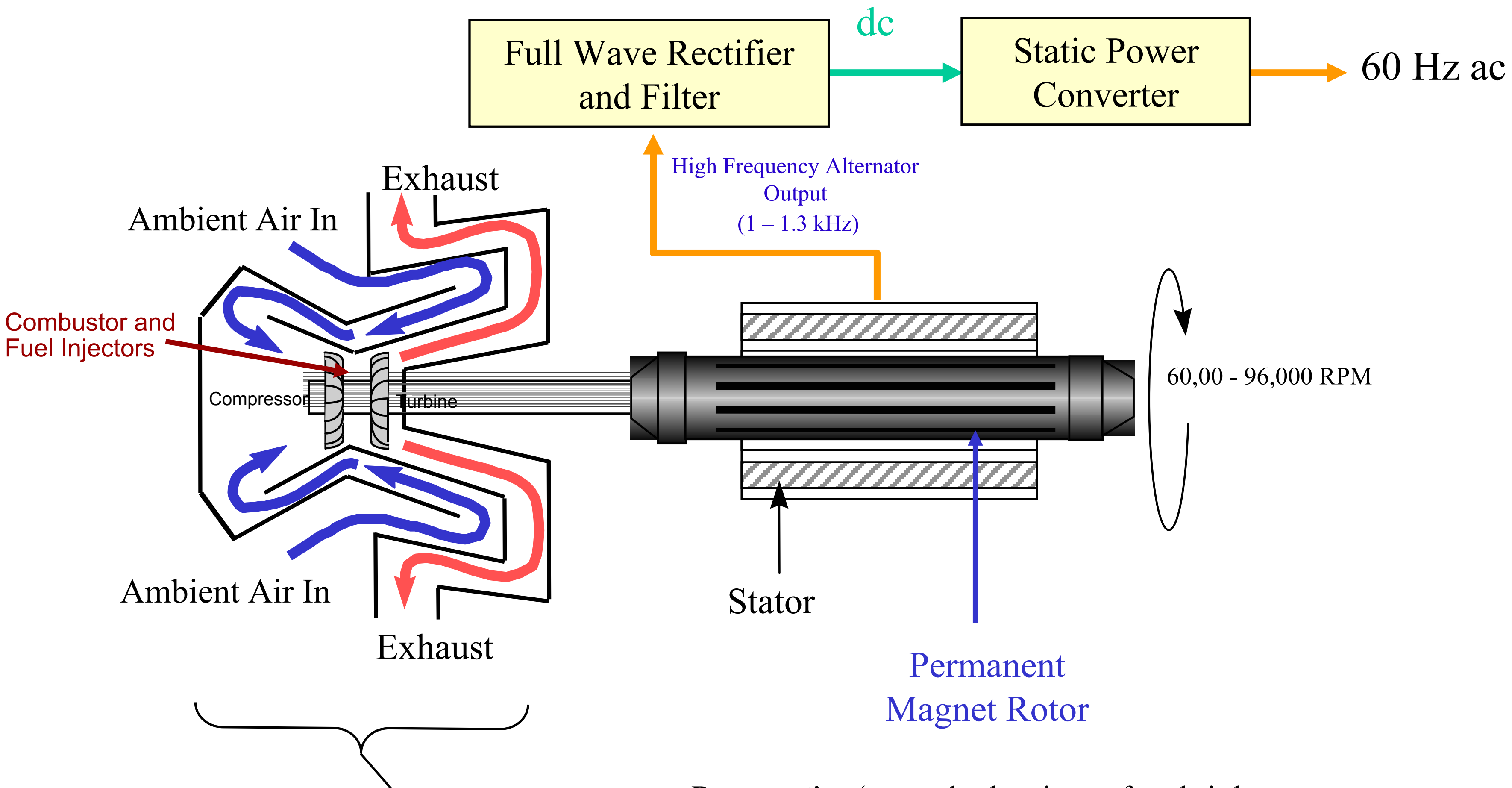
Packaged Enclosure for GE 40 MW Gas Turbine Generator Set



Enclosure for 40 MW Gas Turbine-Generator Set. Source: General Electric Co.



Schematic of Microturbine



Recuperation (means that heat is transferred via heat exchanger from exhaust to intake air)

Select Commercial Microturbines

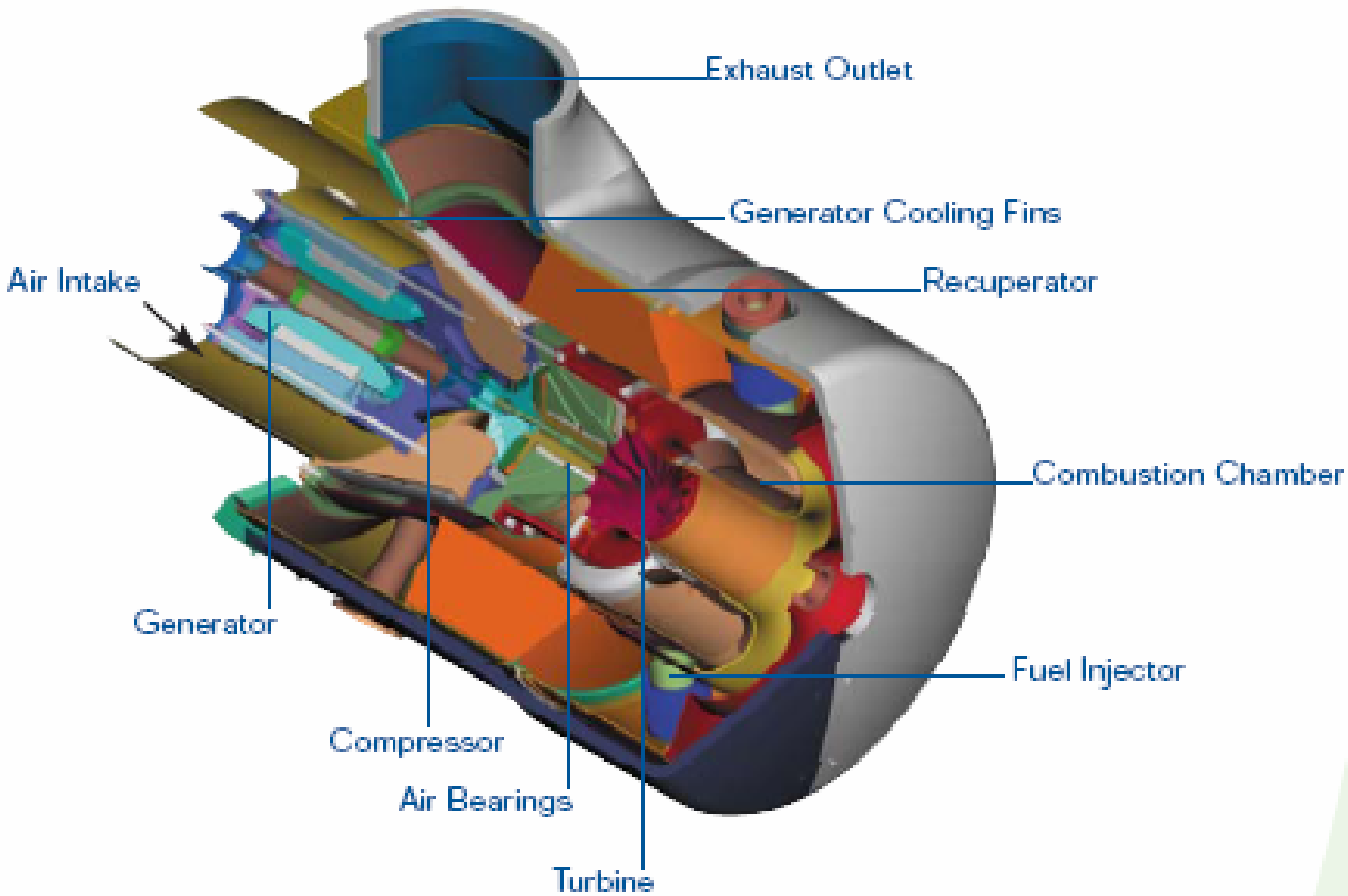
Capstone 30 kW
(First Generation Design)

IR PowerWorks 70 kW

Capstone 30 kW
50 unit farm at Lopez Canyon, LA

Capstone 30 kW
Model C30, Natural Gas, Dual-mode

Capstone C60 MicroTurbine Generator



Capstone C60

NATURAL GAS

Certifications

UL 1741

UL 2200

IEEE 519

CEC Rule 21

NYPSC DG

CARB DG 2003

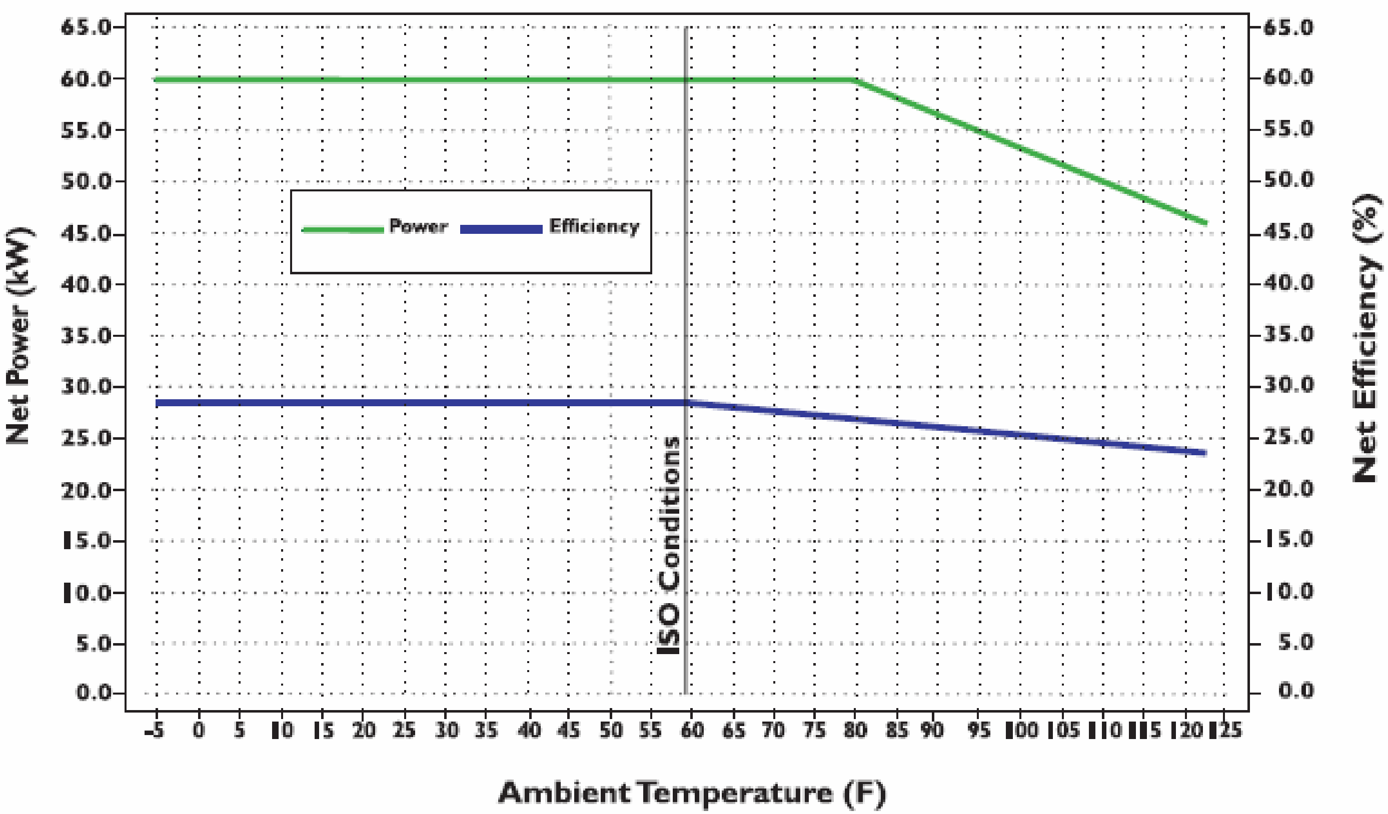
EPA Exempt

WY DEQ Exempt

NEMA 3R / IP 14

Others

C60 Net Power and Efficiency*
at Ambient Temperature, Sea Level



Power:
60 kW net (+0/-2)*
83 kVA max @ 480 VAC

Electrical Efficiency (LHV):
28% (±2)*

Heat Rate (LHV):
12,900 kJ (12,200 Btu) / kWh

Exhaust Temp.:
305˚C (580˚F)

NOx: <9 ppmV @ 15% O_2
(<0.49 lb/MWh)

Fuel:
Natural gas @ 75-80 psig
HHV 849,000 kJ/hr
(804,000 Btu/hr)

PowerWorks.

70L Series Microturbine

Patented Recuperator
- Critical to high efficiency
- Designed for 80,000-hr life

Patented Combustor
- Dry low NOx
- Easily meets stringent environmental regulations

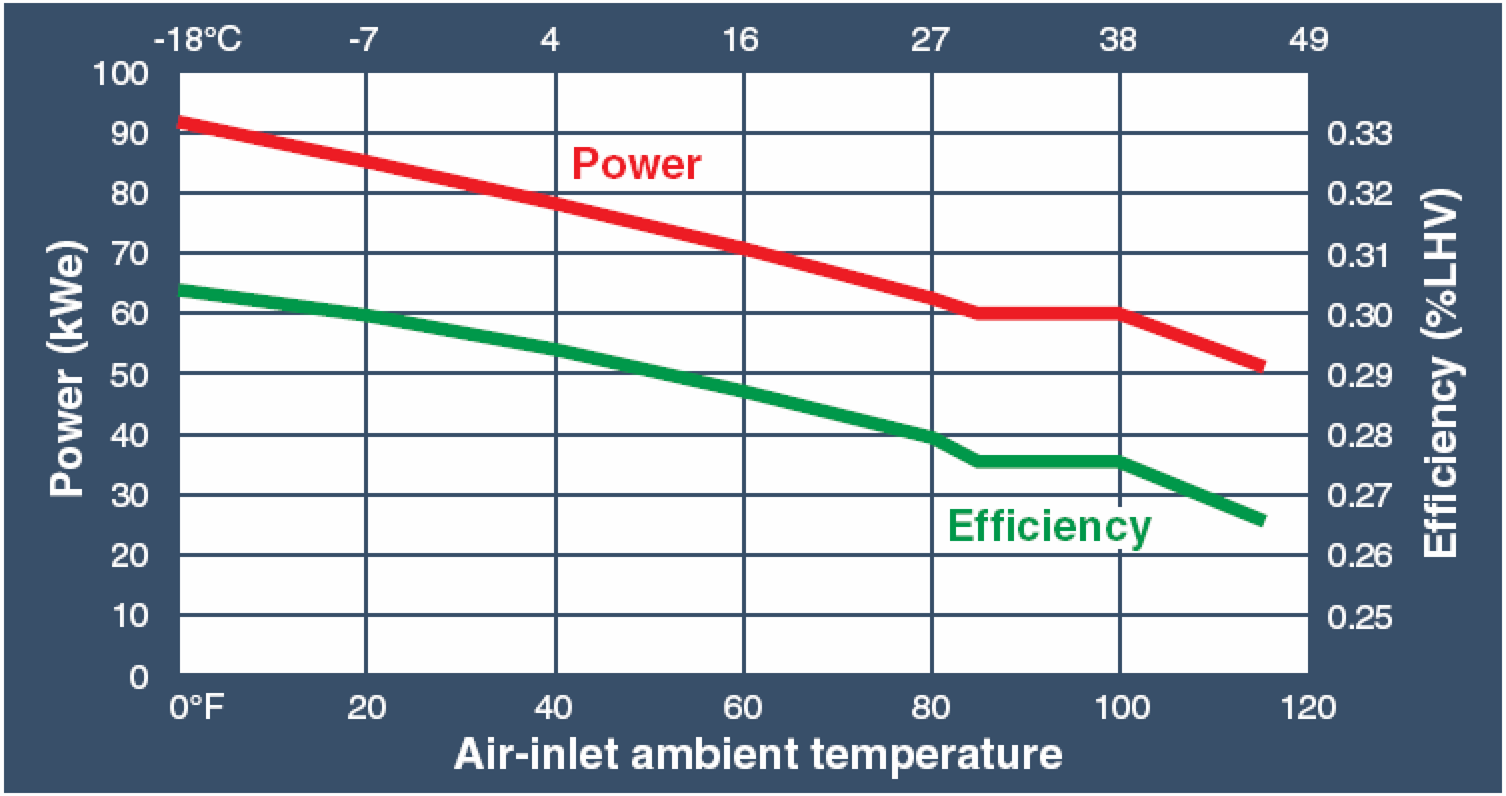
Proven Generator Technology
- Well-understood by utilities
- Same technology used by utilities to power the grid

Integrated Heat Recovery
- Controllable output level
- Small footprint

Fuel-Gas Booster
- Long-life design
- Fully integrated

PowerWorks

70L Series Microturbine



Note - kWe is electrical output at terminals corrected for parasitics, but not including gas-booster power.

IR PowerWorks.

www.irpowerworks.com

70L Series Microturbine

Electrical Performance*

Characteristic	Specification
Nominal Electrical Power (±5)	70 kW@59°F
Maximum Electrical Power (±5)	92 kW@ 0°F
Voltage	480 VAC
Frequency	60 Hz
Type of Service	3 phase, wye, 4-wire ungrounded
Electrical Efficiency LHV (±2)	28% LHV including fuel-gas booster 29% LHV without fuel-gas booster
Heat Rate HHV	13,550 BTU/kWh including fuel-gas booster 13,080 BTU/kWh without fuel-gas booster

* At ISO Conditions (59°F @ sea level, 60% RH) unless otherwise noted

Physical

	L x W x H	Weight
Dimensions	71 x 43 x 87 in 181 x 108 x 222 cm	4850 lb 2200 kg
Noise	78 dBA @ 1 m 58 dBA @ 10 m	

Fuel Requirements

Characteristic	Specification
Input Pressure	4˝ WC to 75 psig
Heat Content	350 to 2500 BTU/scf
Min Temperature	33°F
Max Temperature	115°F

Emissions (Natural Gas)

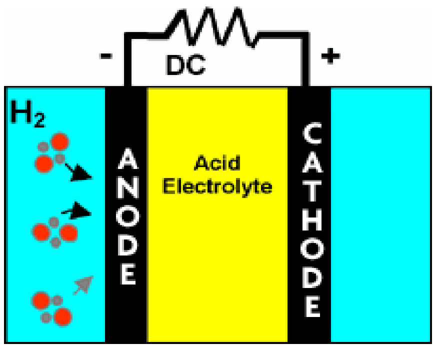
Characteristic	Specification
NOx	< 0.15 lbm/MWh
CO	< 0.5 lbm/MWh

Heat Recovery*

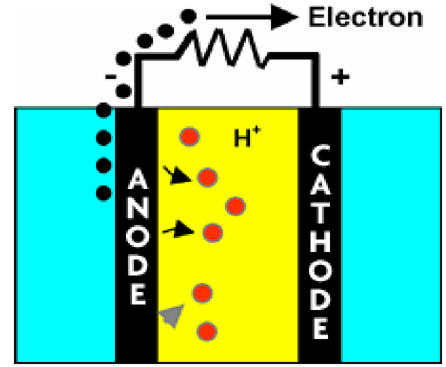
Characteristic	Specification
Engine Exhaust Temp	450°F
Exhaust Gas Flow	1.6 lbm/s
Max Water Flow	30 gpm
Max Water Pressure	125 psig
Max Water Temp	180°F
Suitable for potable applications	

* At ISO Conditions (59°F @ sea level, 60% RH) unless otherwise noted

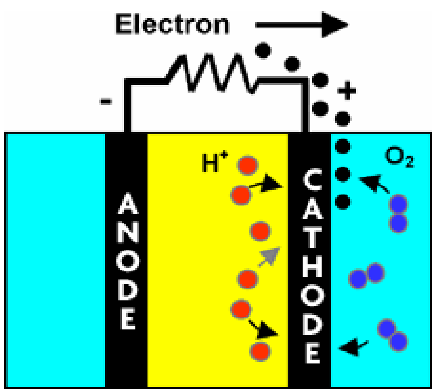
Schematic of a Fuel Cell



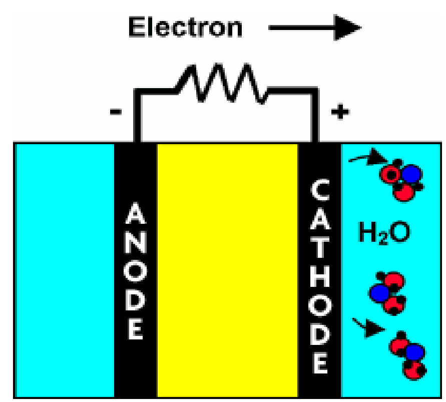
A. Hydrogen gas flows over the anode



B. Electrons are stripped from the hydrogen and flow through the anode to the external circuit



C. Hydrogen ions move through electrolyte to cathode.
Electrons move into cathode from load
Oxygen is introduced to the cathode.



D. Hydrogen ions, electrons, and oxygen combine to form water (steam)

Types of Fuel Cells and Characteristics

PHOSPHORIC ACID

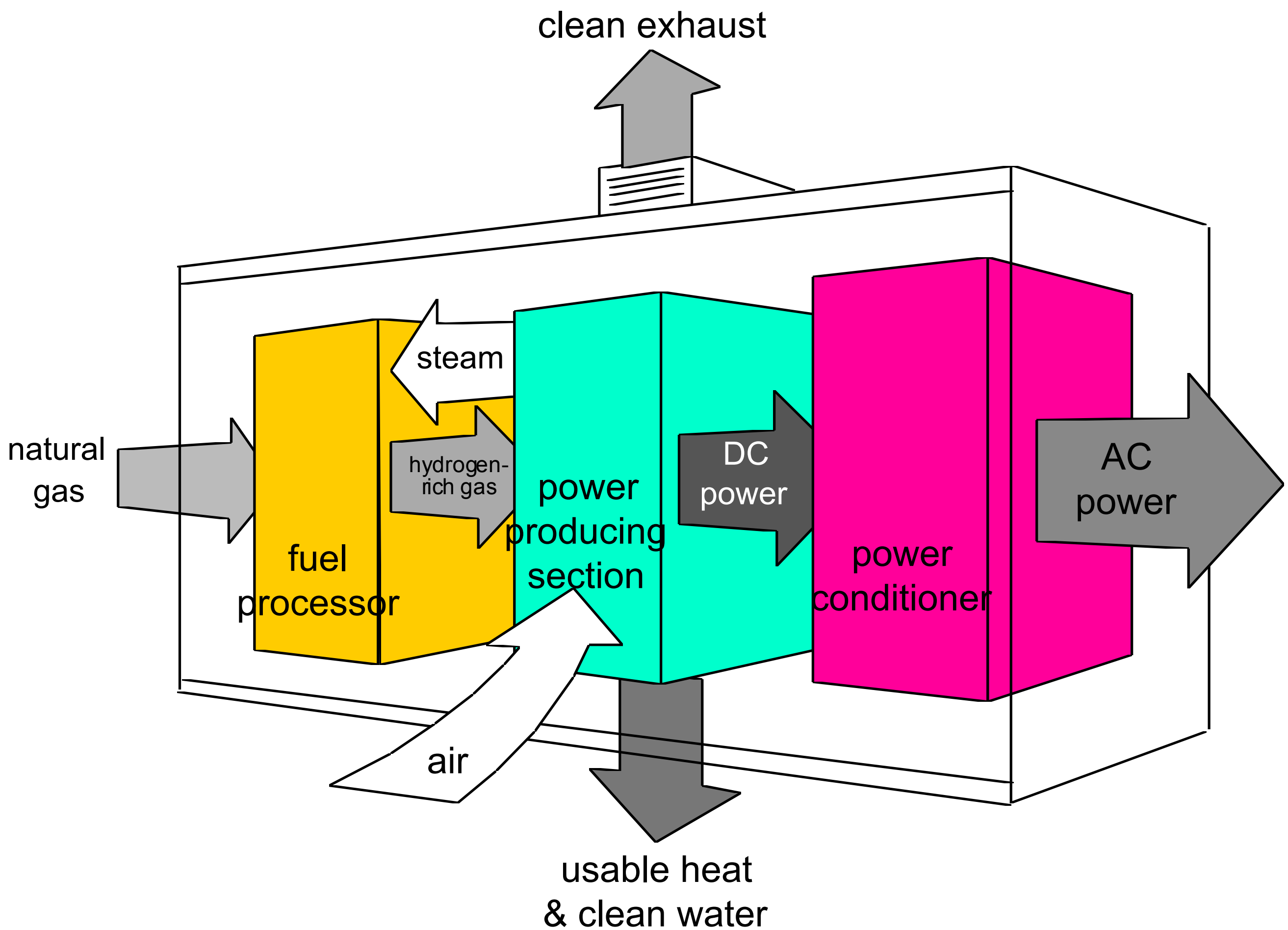
SOLID OXIDE

MOLTEN CARBONATE

PROTON EXCHANGE MEMBRANE

Fuel Cells Overview				
	PAFC	SOFC	MCFC	PEMFC
Commercially Available	Yes	No	Yes	Yes
Size Range	100-200 kW	1 kW - 10 MW	250 kW - 10 MW	3-250 kW
Fuel	Natural gas, landfill gas, digester gas, propane	Natural gas, hydrogen, landfill gas, fuel oil	Natural gas, hydrogen	Natural gas, hydrogen, propane, diesel
Efficiency	36-42%	45-60%	45-55%	30-40%
Environmental	Nearly zero emissions	Nearly zero emissions	Nearly zero emissions	Nearly zero emissions
Other Features	Cogen (hot water)	Cogen (hot water, LP or HP steam)	Cogen (hot water, LP or HP steam)	Cogen (80°C water)
Commercial Status	Some commercially available	Likely commercialization 2004	Some commercially available	Likely commercialization 2003/2004

Schematic of a Fuel Cell System



UTC Fuel Cells
A United Technologies Company

PC25™ Performance Data

Feature	Characteristics
Rated Electrical Capacity	• 200 kW/235kVA
Voltage and Frequency	• 480/277 V, 60 Hz, 3 phase • 400/230 V, 50 Hz, 3 phase
Fuel Consumption	• Natural gas: 2100 cft/h @ 4-14" water pressure • Anaerobic digester gas: 3200 cft/hr at 60% CH_4
Efficiency (LHV Basis)	• 87% Total: 37% Electrical, 50% Thermal
Emissions	• <2 ppmv CO, <1 ppmv NOx and negligible SOx (on 15% O_2, dry basis)
Thermal Energy Available Standard: High heat options:	 • 900,000 Btu/hr @ 140F • 450,000 Btu/hr @ 140F • 450,000 Btu/hr @ 250F

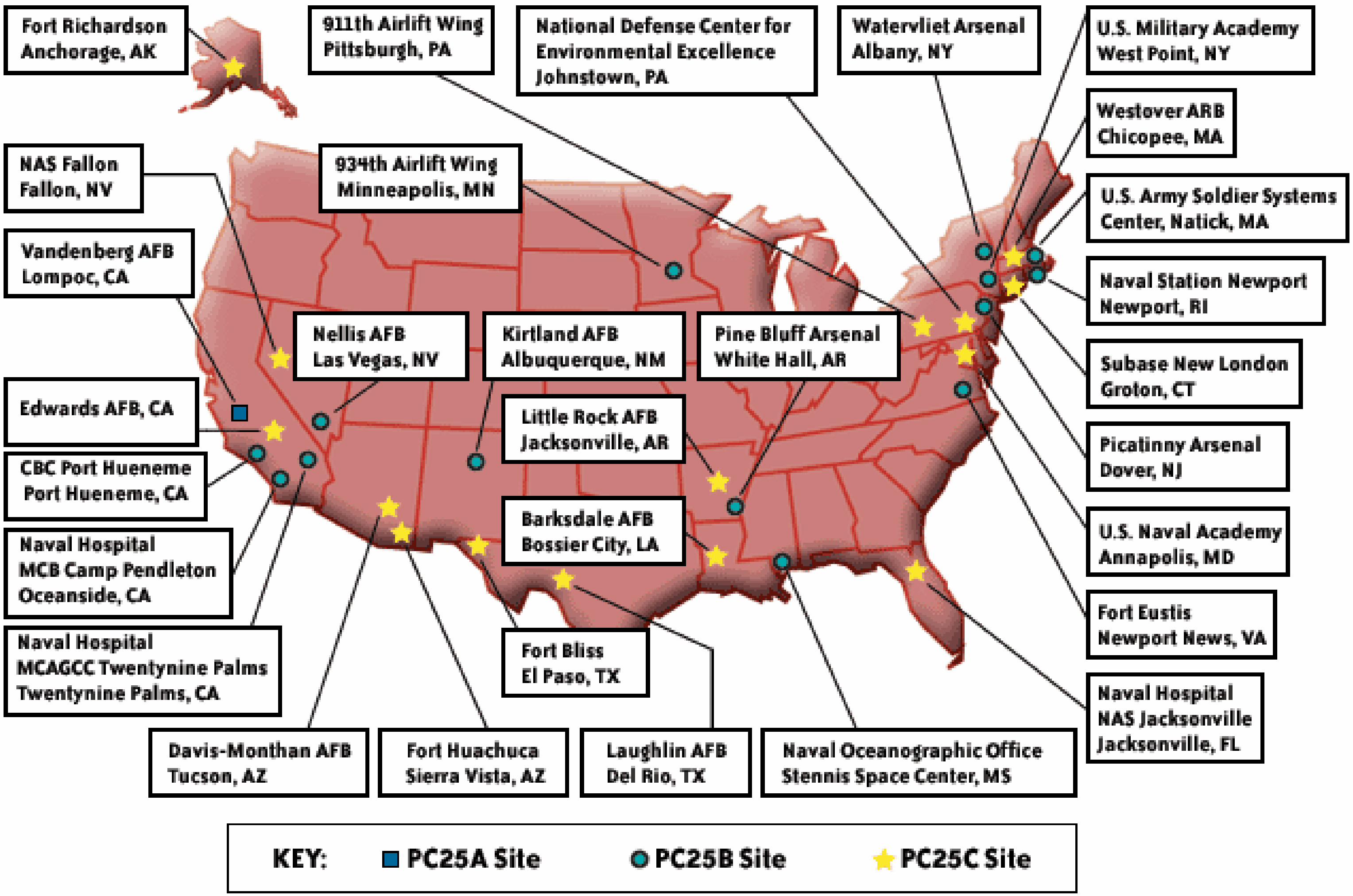
Fuel Cells Provide Reliable Power to U.S. Postal Service Facility in Anchorage, Alaska

Set against the Chugach Mountains, five fuel cells supply reliable and clean power to the USPS facility.

The Mail Processing and Distribution Facility, adjacent to the Anchorage International Airport, is key to the Alaska mail system.

U.S. Department of Energy
Energy Efficiency and Renewable Energy

DoD PAFC Fuel Cell Sites



plugpower FUEL CELL SYSTEMS

GenSys™

	PRODUCT CHARACTERISTICS	5C	4C
Physical	Size (L x W x H)	84 1/2" x 32" x 68 1/4"	●
Performance	Continuous Power Rating	5kWe (9kWth)	4kWe (9kWth)
	Power Output	2.5-5kWe (3-9kWth)	2.5-4kWe (3-9 kWth)
	Voltage	120/240 VAC @ 60Hz	100/230 VAC @ 50Hz
	Power Quality	IEEE 519	●
	Emissions	NOX <1ppm	●
		SOX <1ppm	●
		Noise <60 dBa @ 1 meter	●
Operating Conditions	Temperature	0°F to 104°F	●
	Elevation	0 to 6000 feet	●
	Installation	Outdoor	●
	Electrical Connection	Grid Parallel	●
	Fuel	Natural Gas	●
Certifications	Power Generation	CSA International	●
	Power Conditioning	UL	—
	Electromagnetic Compliance	FCC Class B	—

plug power FUEL CELL SYSTEMS

GenSys™

1 Fuel Processing Module
converts natural gas into hydrogen.

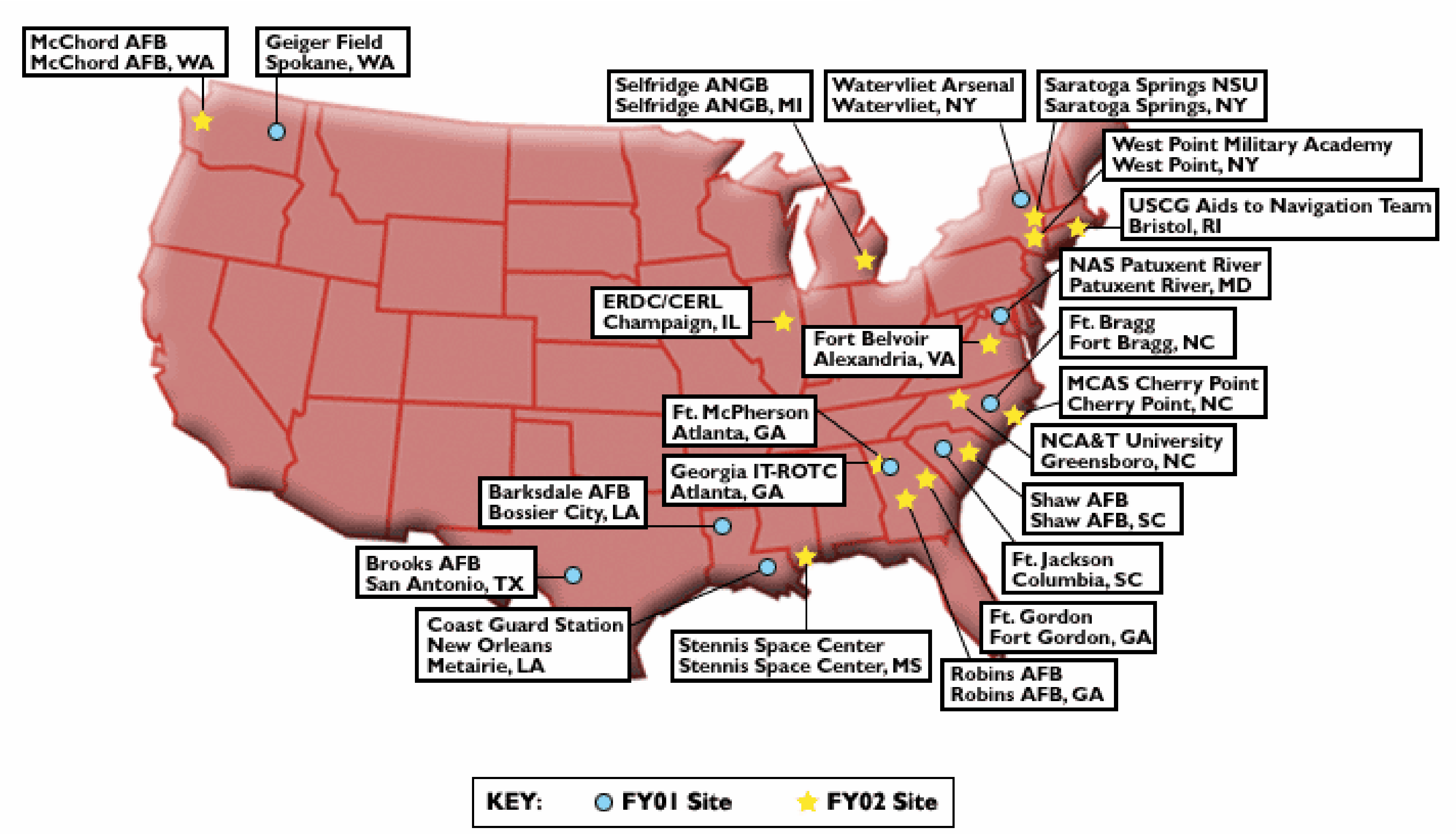
2 Power Generation Module
combines hydrogen with air to create DC power.

3 Power Electronics Module
converts DC power to AC power for use in residential or commercial applications.

4 Energy Storage Module
ensures continuity of power during system transients.

5 Thermal Management Module
optimizes system performance and provides heat for use in the facility.

DoD PEM Fuel Cell Sites



DoD PEM Fuel Cell Performance

Fuel Cell Performance

Officers' Quarters (4 units) : 01/15/2002 - 01/21/2003

Cummulative Operating Hrs	32,493 Hours	**Capacity Factor**	46%
Total Electric Output	81,362 kWh	**Availability**	91%
Avg. Output for Site	10.0 kW	**Electrical Efficiency**	23.3%

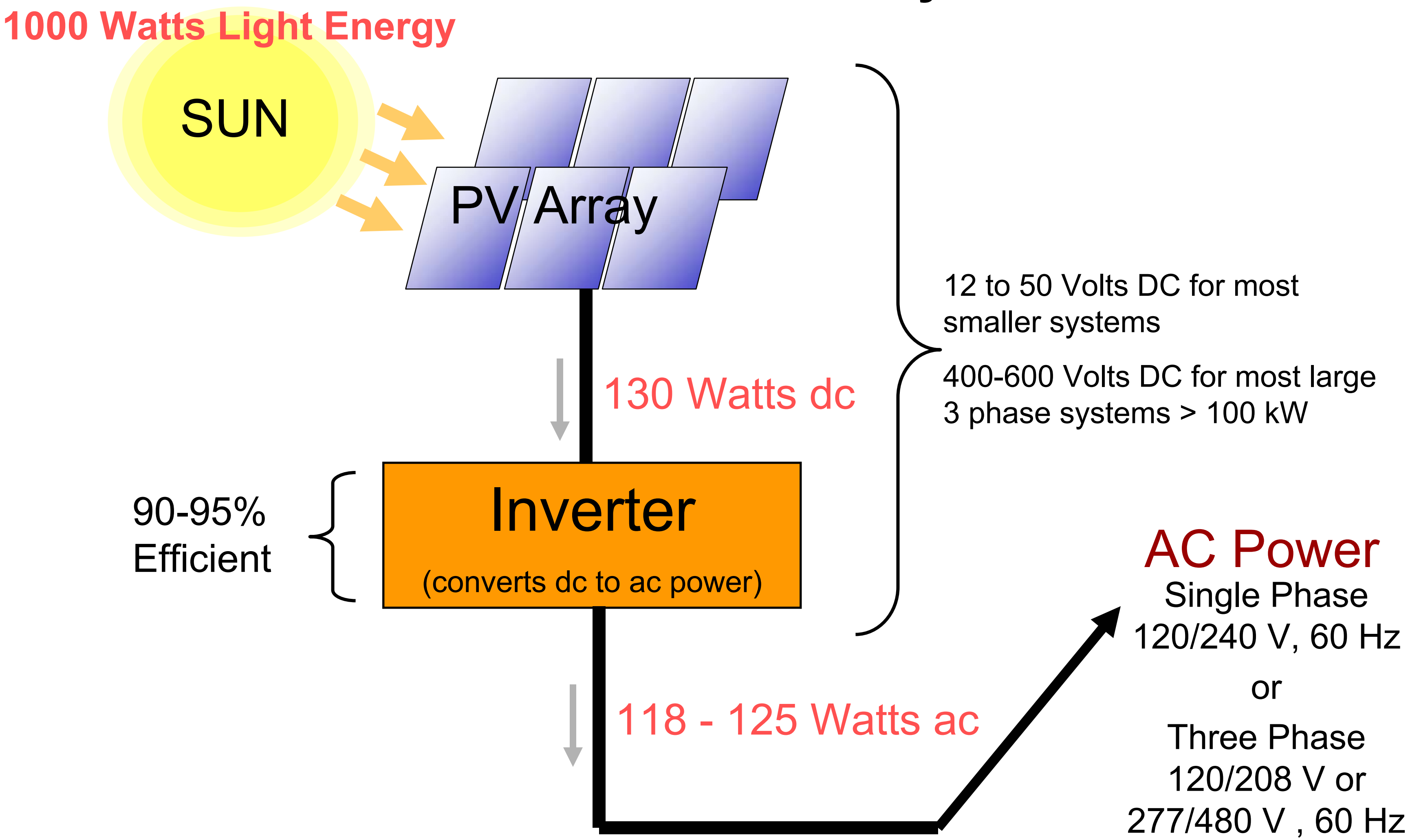
Research Facility (3 units) : 01/18/2002 - 01/21/2003

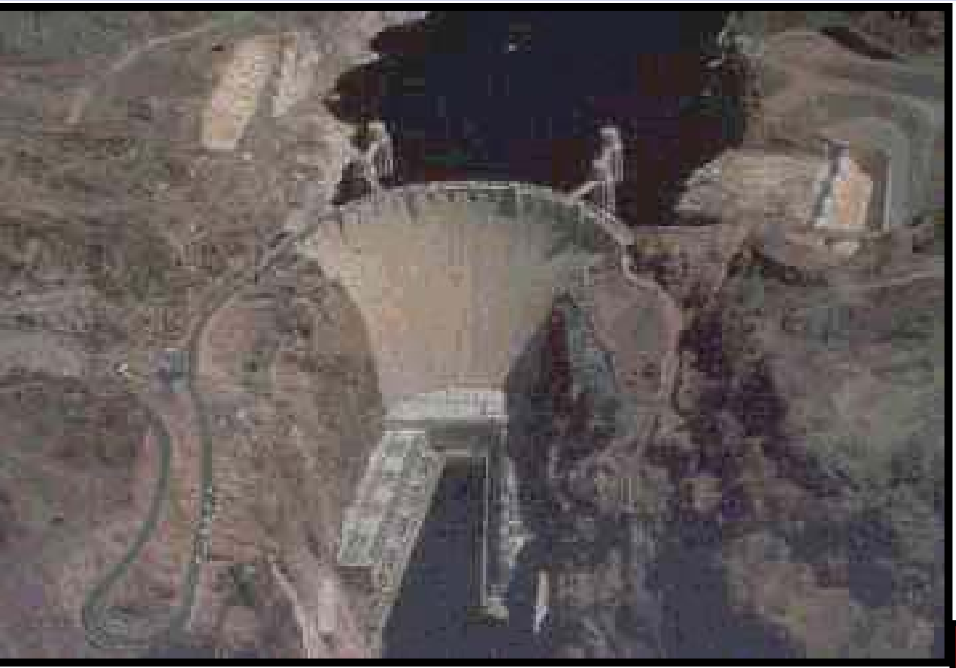
Cummulative Operating Hrs	25,417 Hours	**Capacity Factor**	51%
Total Electric Output	68,187 kWh	**Availability**	96%
Avg. Output for Site	8.0 kW	**Electrical Efficiency**	25.4%

Manufacturing Facility (3 units) : 01/18/2002 - 01/21/2003

Cummulative Operating Hrs	25,096 Hours	**Capacity Factor**	49%
Total Electric Output	65,008 kWh	**Availability**	95%
Avg. Output for Site	7.8 kW	**Electrical Efficiency**	24.1%

Schematic of a PV System

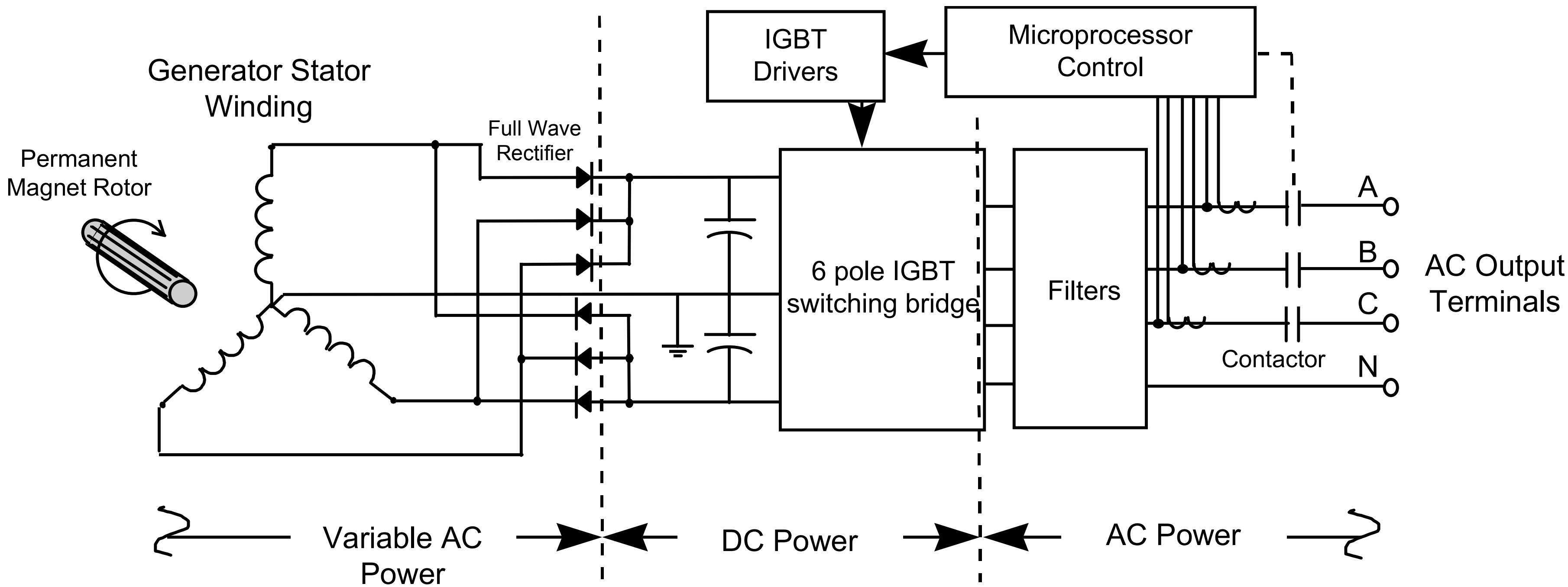




Lake Mead formed by Hoover Dam has an area of 640 km^2. The dam has a capacity of 2,080 MW. If the same area was covered with 15% efficient solar modules, the peak solar output at noon could be at least 60,000 MW!

This includes a large margin for DC-AC inverter loss and the spacing between PV array rows

Schematic of a Wind Turbine



New Mexico Wind Energy Center

- The New Mexico Wind Energy Center consists of 136 turbine towers, each measuring 210 feet in height.
- The towers sit on 9,600 acres of private and state-owned land.
- The turbine blades exceed 110 feet in length.
- The wind center is located 20 miles northeast of Fort Sumner and straddles Quay and DeBaca counties. It is about 170 miles from Albuquerque and may be seen from New Mexico 252 and U.S. 84.
- The wind center will have a peak output of about 200 megawatts of electricity, or about 1.5 megawatts per turbine. The turbines require 8 mph winds to produce electricity and will continue to produce electricity in winds up to 55 mph.

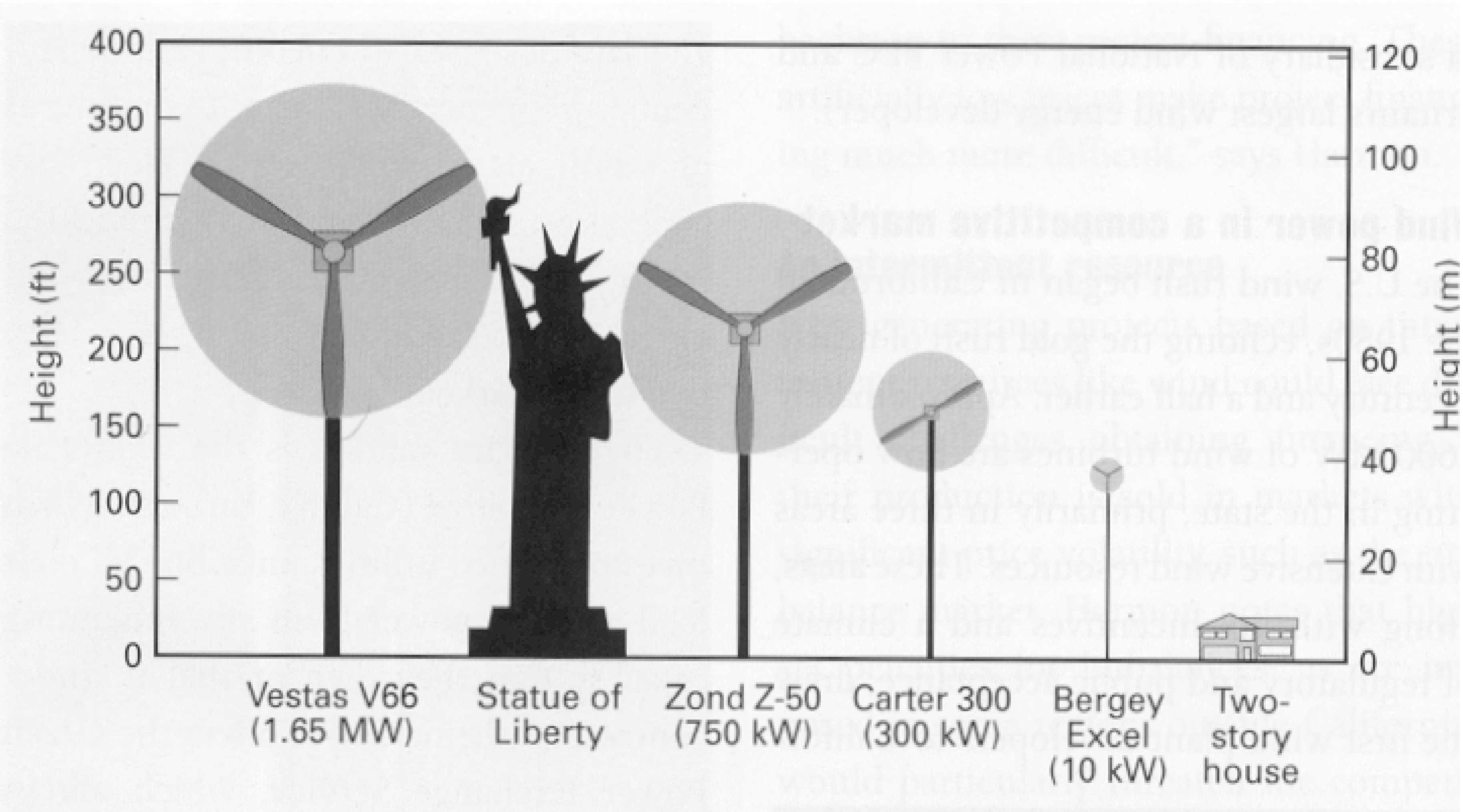
PNM®

New Mexico Wind Energy Center

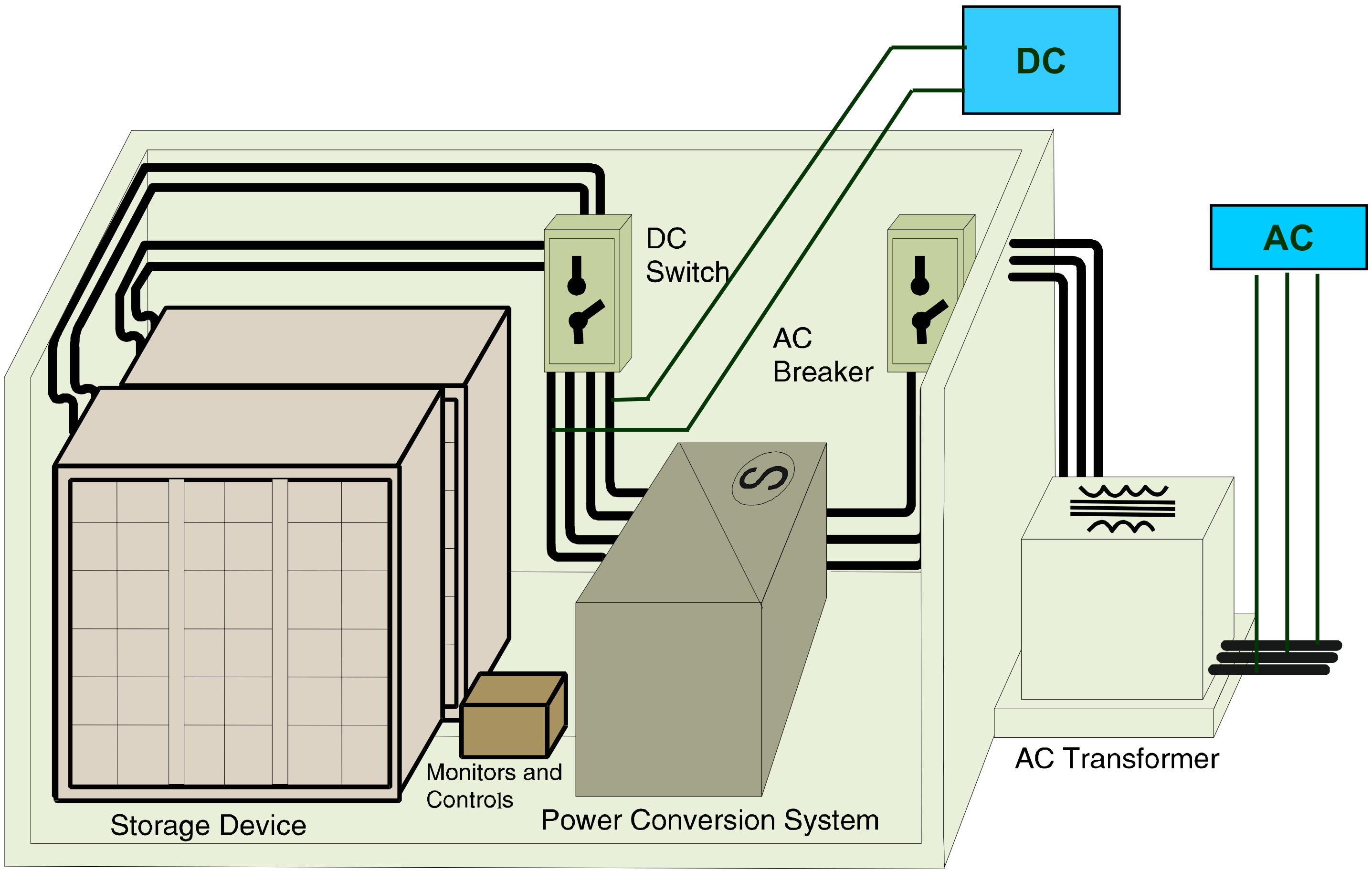
PNM®

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Commercial Readiness and Manufacturers



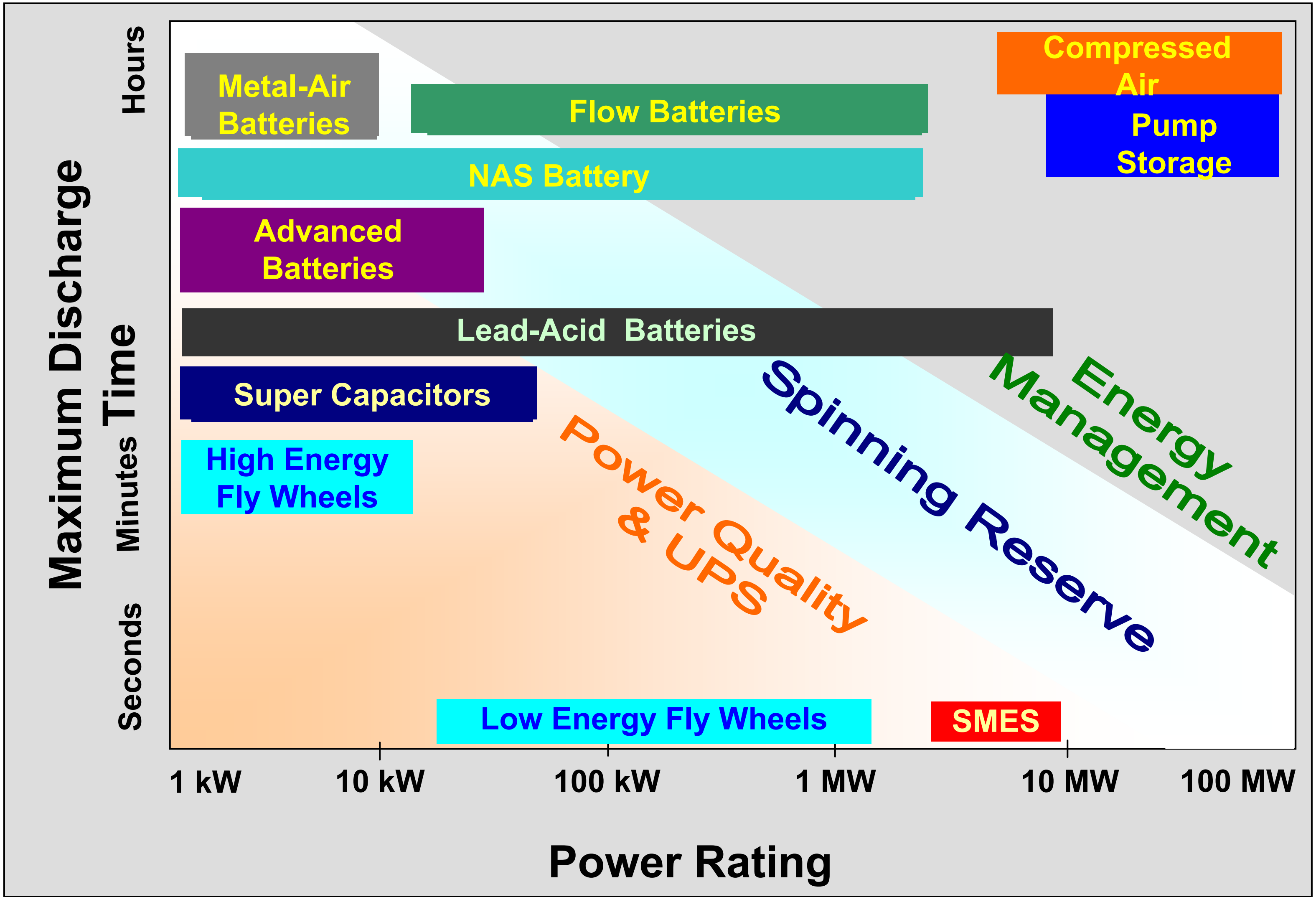
Schematic of a Battery/Energy Storage System



Storage Technologies	Main Advantages (relative)	Disadvantages (Relative)	Power Application	Energy Application
Pumped Storage	High Capacity, Low Cost	Special Site Requirement		●
CAES	High Capacity, Low Cost	Special Site Requirement, Need Gas Fuel		●
Flow Batteries: PSB VRB ZnBr	High Capacity, Independent Power and Energy Ratings	Low Energy Density	◑	●
Metal-Air	Very High Energy Density	Electric Charging is Difficult		●
NaS	High Power & Energy Densities, High Efficiency	Production Cost, Safety Concerns (addressed in design)	●	●
Li-ion	High Power & Energy Densities, High Efficiency	High Production Cost, Requires Special Charging Circuit	●	○
Ni-Cd	High Power & Energy Densities, Efficiency		●	◑
Other Advanced Batteries	High Power & Energy Densities, High Efficiency	High Production Cost	●	○
Lead-Acid	Low Capital Cost	Limited Cycle Life when Deeply Discharged	●	○
Flywheels	High Power	Low Energy density	●	○
SMES, DSMES	High Power	Low Energy Density, High Production Cost	●	
E.C. Capacitors	Long Cycle Life, High Efficiency	Low Energy Density	●	◑

●	Fully capable and reasonable
◑	Reasonable for this application
○	Feasable but not quite practical or economical
None	Not feasable or economical

Energy Storage Applications/Capabilities



Urenco Flywheel System

Characteristic	Value
Output Power	100 kW
Output Voltage	Constant Value Adjustable between 600 and 750V dc
Discharging time at maximum power	30 seconds
Steady state losses	Approx. 1200W
Charging / Discharging efficiency	Greater than 90% for one operation
Operating Speed	36,000 - 12,000 r.p.m
Temperature Range	-20C to +40C
Design Life	Minimum 20 years
Number of full discharges	Minimum 10 million
Maintenance	None for rotating parts

Table 2. Summary of Cost and Performance Parameters for Distributed Generation Technologies

Technology	Size Range (kW)	Installed Cost ($/kW)[b]	Heat Rate (BTU/ kWh_e)	Approx. Efficiency (%)	Variable O&M ($/kWh)	Emissions[a] (lb/kWh)	
						NO_x	CO_2
Diesel Engine	1-10,000	350-800	7,800	45	0.025	0.017	1.7
Natural Gas Engine	1-5,000	450-1,100	9,700	35	0.025	0.0059	0.97
Natural Gas Engine w/ CHP[c]	1-5,000	575-1,225	9,700	35	0.027	0.0059	0.97
Dual Fuel Engine	1-10,000	625-1,000	9,200	37	0.023	0.01	1.2
Microturbine	15-60	950-1,700	12,200	28	0.014	0.00049	1.19
Microturbine w/ CHP[c]	15-60	1,100-1,850	12,200	28	0.014	0.00049	1.19
Combustion Turbine	300-10,000	550-1,700	11,000	31	0.024	0.0012	1.15
Combustion Turbine w/ CHP[c]	300-10,000	700-2,100	1,100	31	0.024	0.0012	1.15
Fuel Cell	100-250	5,500+	6,850	50	0.01-0.05	0.000015	0.85
Photovoltaics	Limited by Available Space	7,000-10,000	--	N/A	0.002	0	0
Wind Turbine	0.2-5,000	1,000-3,000	--	N/A	0.01	0	0
Battery	1-1,000	1,100-1,300	--	70	0.01	[d]	[d]
Flywheel	2-1,600	400	--	70	0.004	[d]	[d]
SMES	750-5,000	600	--	70	0.02	[d]	[d]
Hybrid Systems	1-10,000	[f]	[e]	[e]	[e]	[e]	[e]

[a] Nationwide utility averages for emissions from generating plants are 0.005 lb/kWh of NO_x and 1.2 lb/kWh of CO_2.

[b] The high end of the range indicates costs with NO_x controls for the most severe emissions limits internal combustion technologies only.

[c] Although the electric conversion efficiency of the prime mover does not change, CHP significantly improves the fuel utilization efficiency of a DER system.

[d] Storage devices have virtually no emissions at the point of use. However, the emissions associated with the production of the stored energy will be those from the generation source.

[e] Same as generation technology selected.

[f] Add cost of component technologies.

References and Websites

Combined Heating, Cooling and Power Handbook: Technologies and Applications, by Neil Petchers. Fairmont Press, Inc.; 2003

Small is Profitable – The Hidden Economic Benefits of Making Electrical Resources the Right Size. By Amory B. Lovins, et al.; 2002

Websites:

FEMP Publications: http://www.eere.energy.gov/femp/information/download_pubs.cfm

Capstone Microturbines: http://www.microturbine.com/

Ingersoll Rand, PowerWorks Microturbines: http://www.irpowerworks.com/

United Technologies 200 kW Fuel Cells: http://www.utcfuelcells.com

Anchorage, AK, Postal Facility Fuel Cell Project: http://www.eere.energy.gov/femp/pdfs/usps_fuel_cells.pdf

DoD PAFC and PEM Projects: http://www.dodfuelcell.com/

Plug Power 5 kW GenSys PEM Fuel Cells: http://www.plugpower.com/products/

Public Service Company of New Mexico (PNM) Wind Energy Project: http://www.pnm.com/systems/nmwec.htm

Electricity Storage Association: http://www.electricitystorage.org/

Caterpillar Flywheel UPS: http://www.caterpillar.com/industry_solutions/shared/electric_power/cat_UPS/cat_UPS.html

Caterpillar Recip. Engines:
http://www.caterpillar.com/products/engines_n_power_systems/shared/electric_power/electric_power.html

URENCO Flywheel Systems: http://www.urenco.com/other_products.htm

Power Quality 2.5 MW/30 sec S and C PureWave System: http://www.sandc.com/edocs_pdfs/edoc_001731.pdf